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DEVELOPMENT AND ASSESSMENT OF TRAFFIC-RELATED EMISSION ABATEMENT MEASURES FOR THE MADRID CITY (SPAIN) THROUGH THE WRF-SMOKE-CMAQ MODELLING SYSTEM

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OUTLINE

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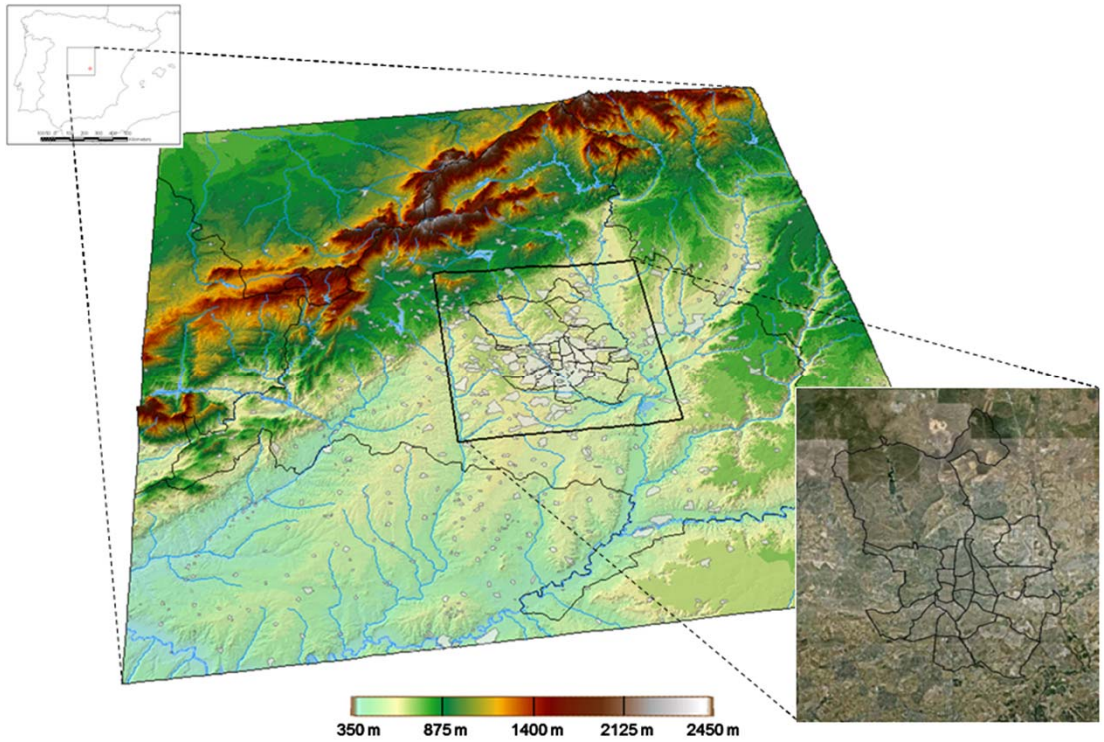
1. Introduction

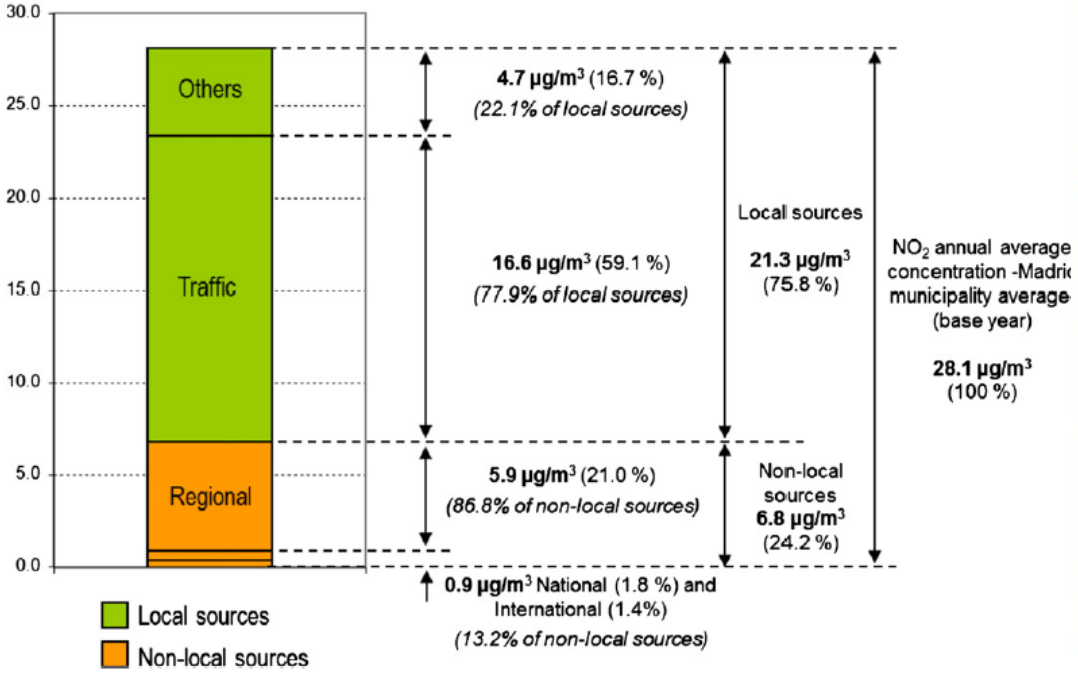
- As environmental standards become more stringent (e.g. European Directive 2008/50/EC), more reliable modelling tools are needed to simulate measures and plans that may effectively tackle air quality exceedances, common in large cities across Europe, particularly for NO_2.

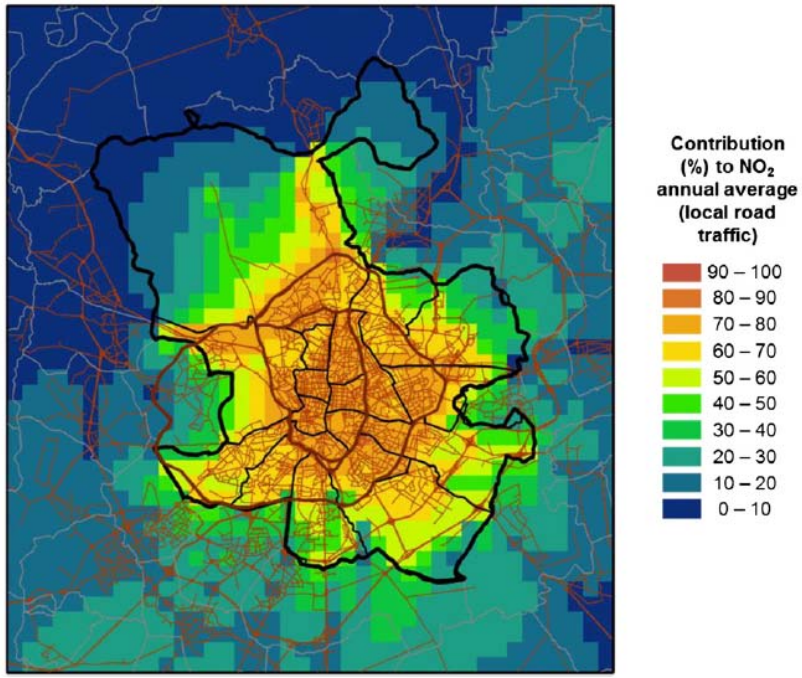
- This is the case of Madrid (Spain), 3.4 million inhabitants in the city, more than 5 million people in the metropolitan area



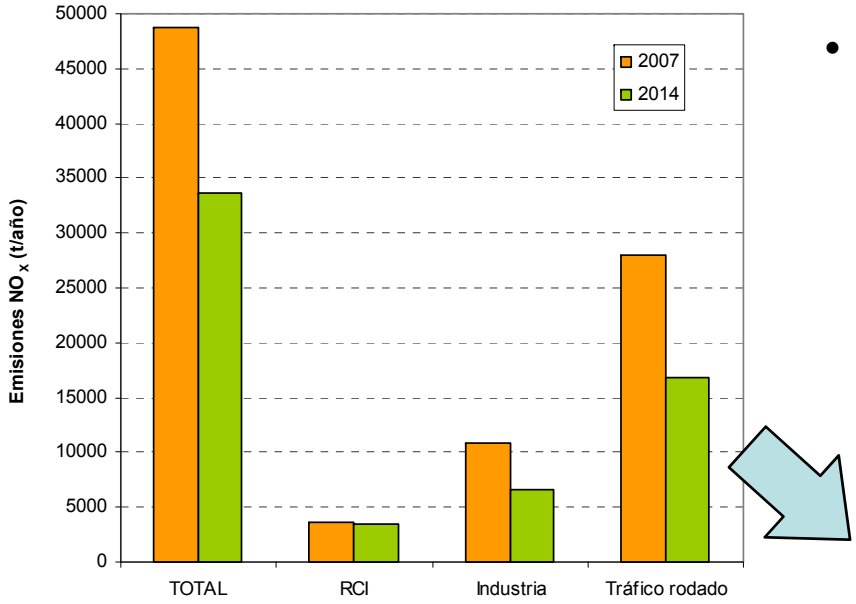
The Madrid Air Quality Plan (AQP)

- Madrid enacted a local AQP in 2012 to meet the NO_2 standards by the end of 2014
- It included a package of 70 measures, most of them aimed at the road transport sector





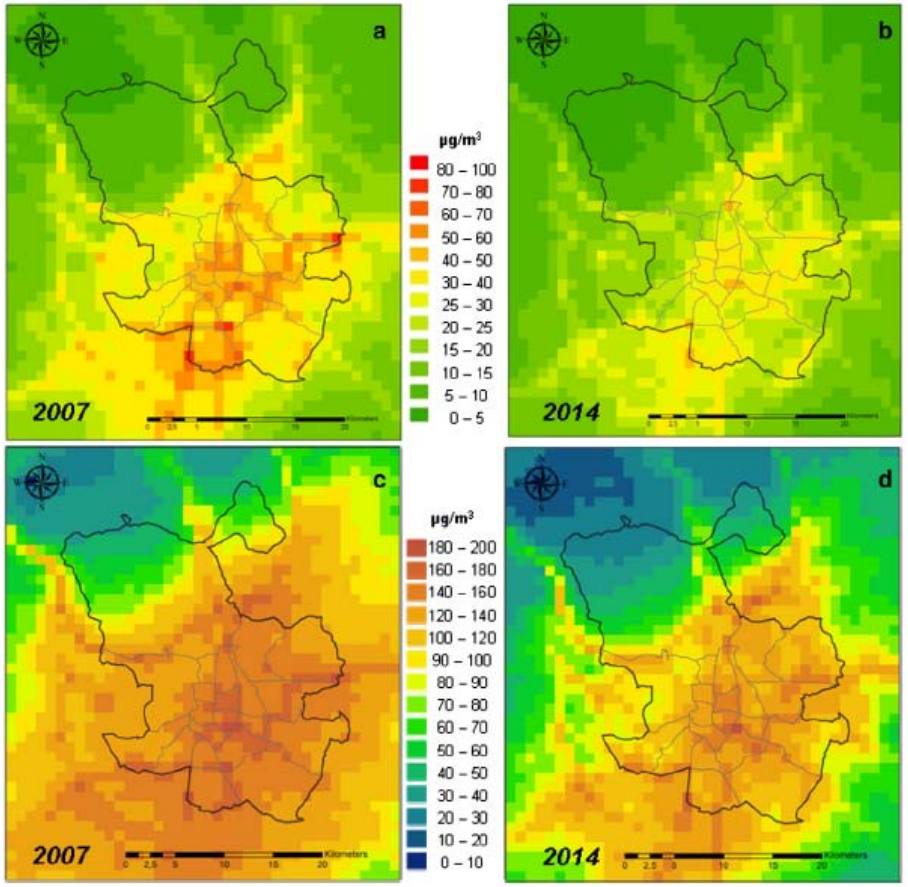
Figures from Borge et al., 2014 (STOTEN)



- A global decrease of 31% in NO_X emissions is expected (40% in the road transport sector)

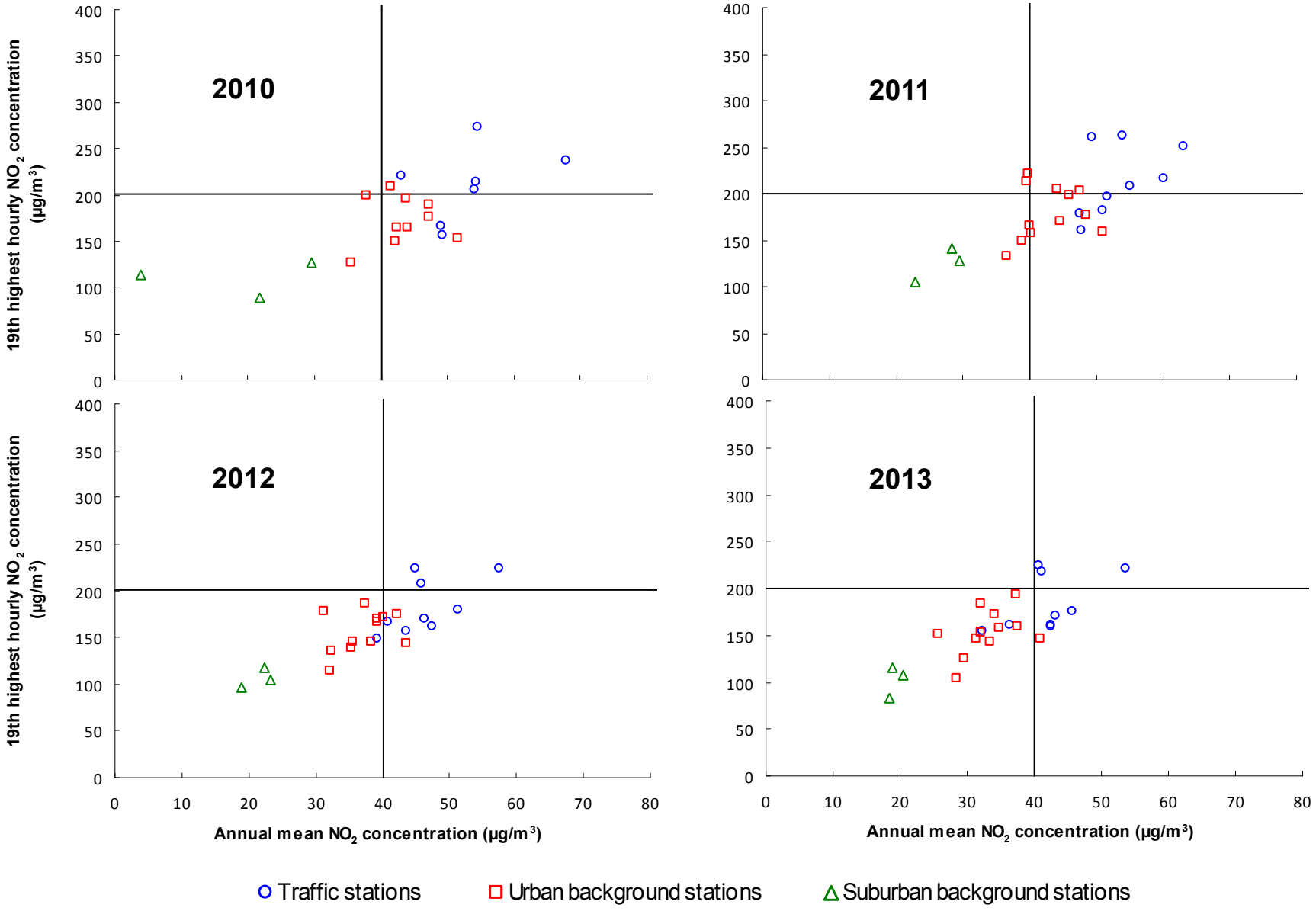
- Annual NO_2 levels reduced by 34% as an average; approximately 15 µg/m^3 in the city center
- Important impact in the metropolitan area (-7 µg/m^3 as an average in the modeling domain)

NO_2 annual mean (Annual LV)



NO_2 annual 1h 99.8th percentile (1-h LV)

Observed NO_2 values (corresponding to the annual and hourly NO_2 limit values defined in the European AQ Directive) in the Madrid air quality monitoring network for the years 2010-2013

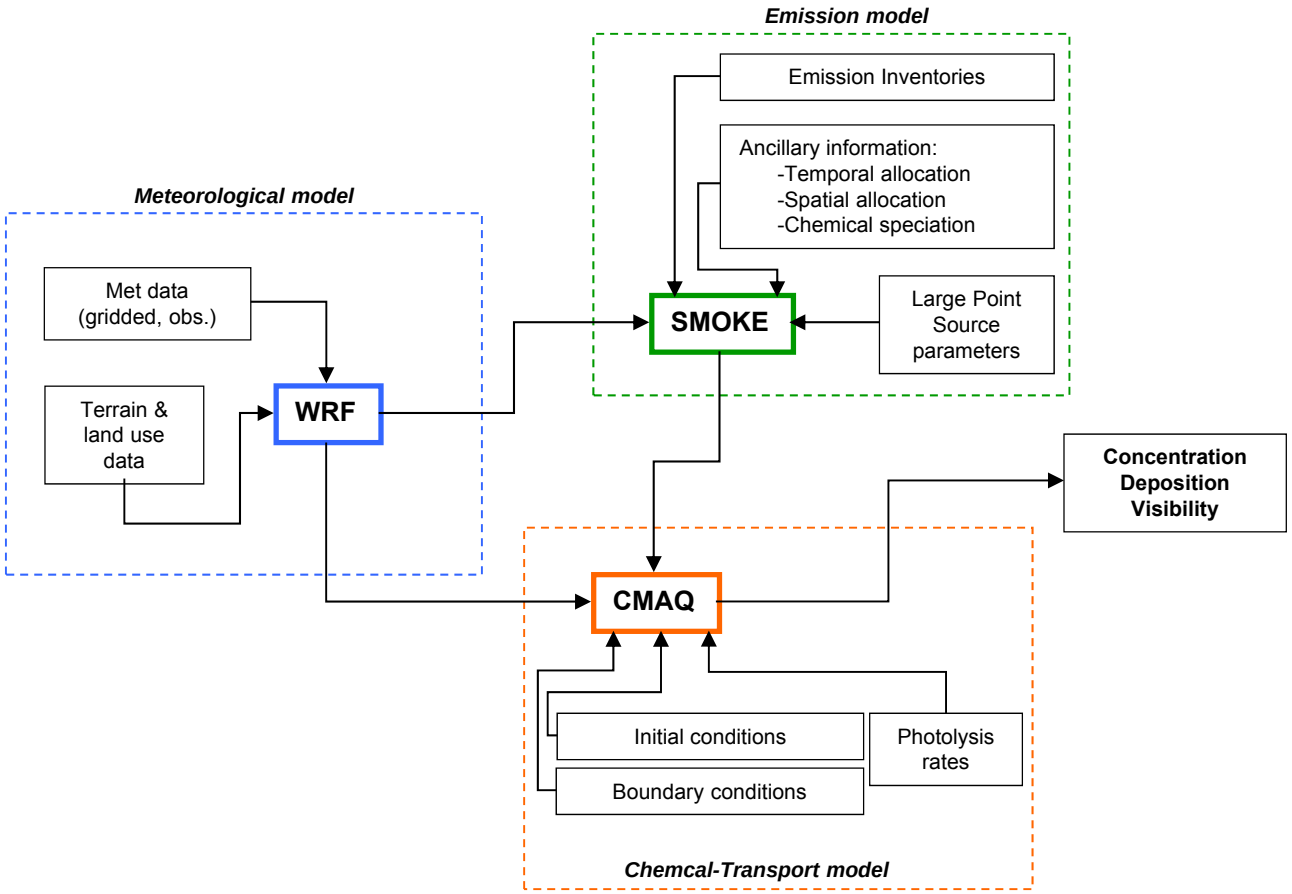


- According to the simulations performed, compliance may be expected by the end of 2014
- Although:
  - Additional microscale measures (and modelling) for particular points are needed
  - Additional, **temporal measures to be applied during high-pollution episodes** must be considered and assessed

- The effect of road traffic access restriction under a 10-day high pollution episode to the city centre are modelled and discussed in this work

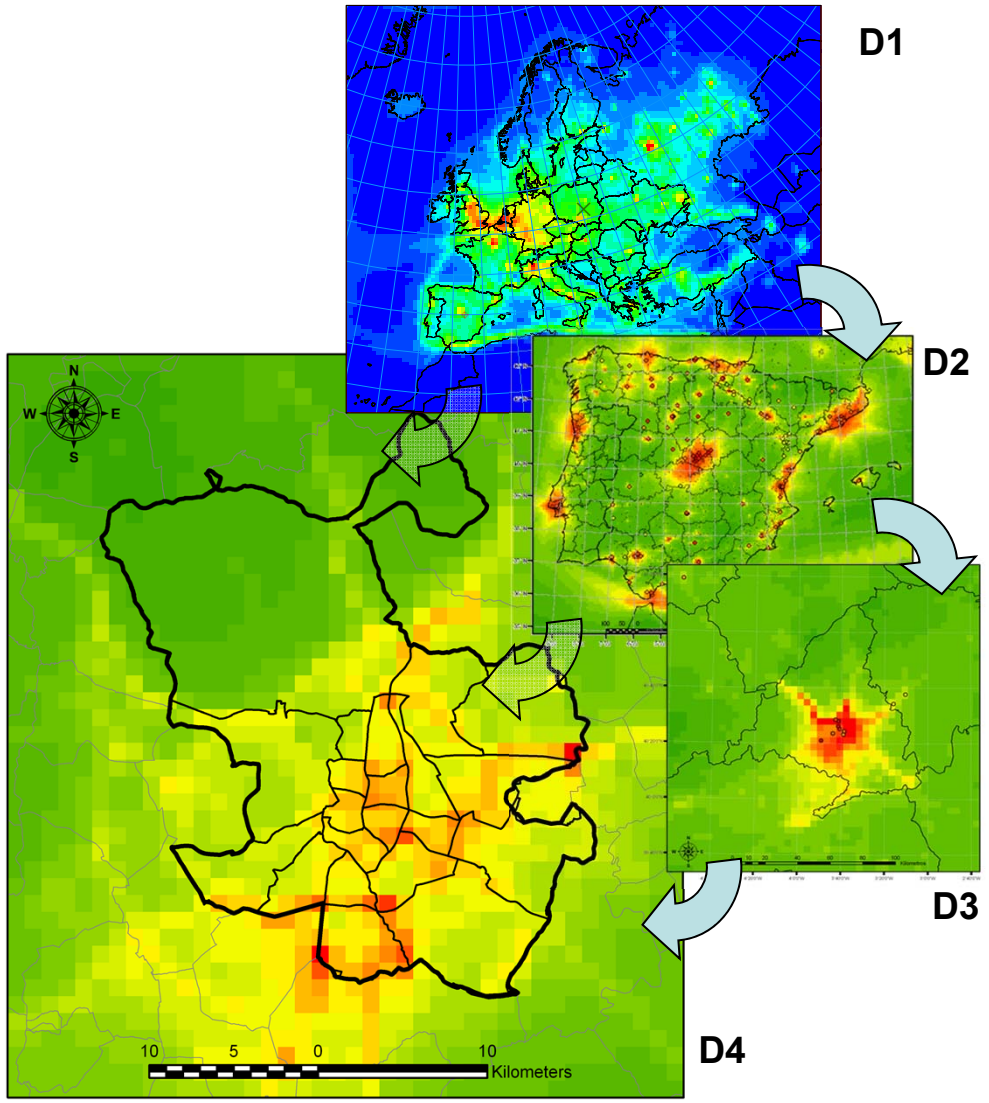
2. Methodology

Air quality modelling system



- Four nested domains can consistently describe air pollution processes from continental to urban scale
- Suitable to estimate contributions from different geographic areas (international, national, regional and local)

Domain	Spatial resolution (km)	Dimensions (km)		Vertical levels
		x	y	
D1	48	6144	5376	30
D2	16	1200	960	
D3	4	192	192	
D4	1	40	44	

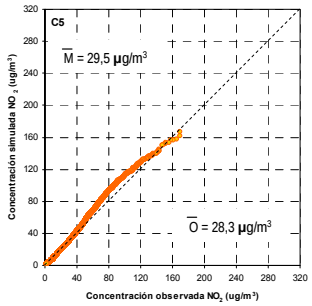


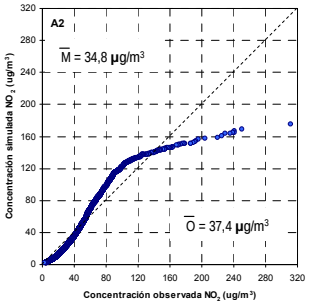
- The system is able to depict urban background levels (e.g. NO_2)

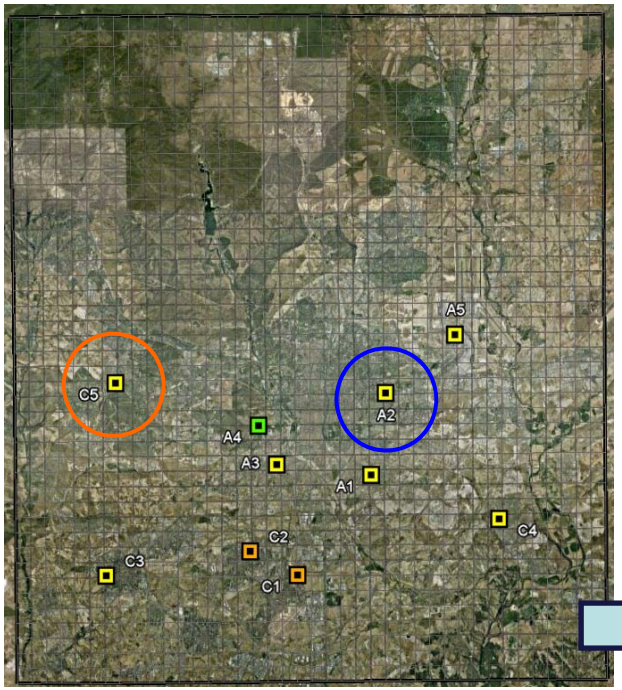
Relative Directive Error (RDE)

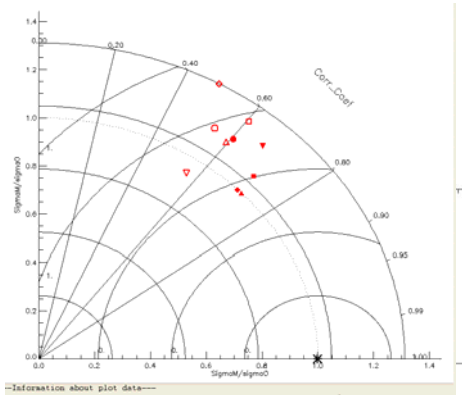
Directive 2008/50/EC

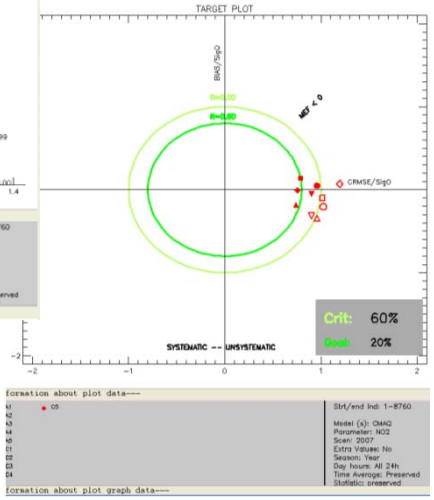
$$RDE = \frac{|O_{LV} - M_{LV}|}{LV} \quad *$$











NO_2 uncertainty (MRDE)

Hourly VL = 23,7 %

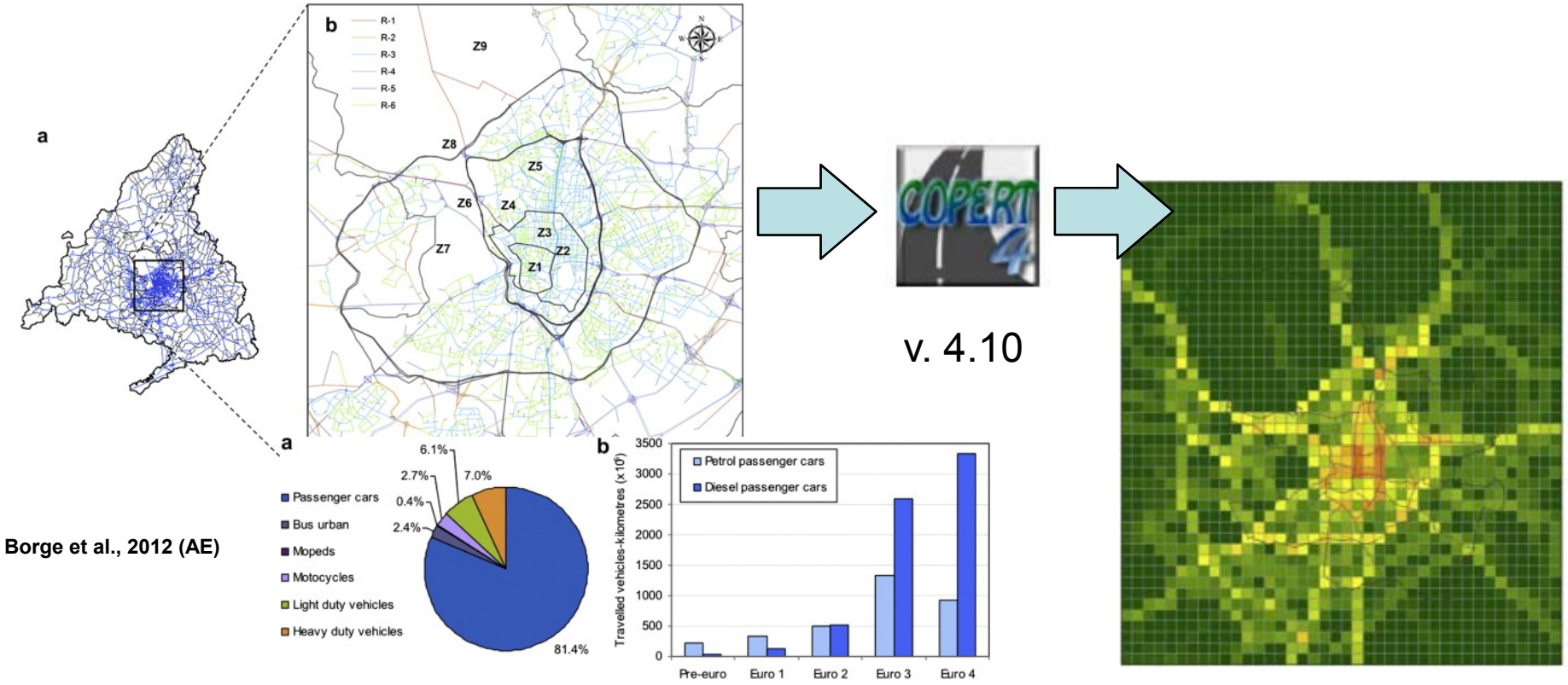
Annual VL = 22,4 %

- Acceptable performance
- (MB = -2.2 µg/m³; r = 0.63; MFB = -14.1%...)

* where O_{LV} is the closest observed concentration to the limit value concentration (LV) and M_{LV} is the correspondingly ranked modelled concentration. The maximum of this value found at 90% of the available stations is then the Maximum Relative Directive Error (MRDE).

Emission modelling

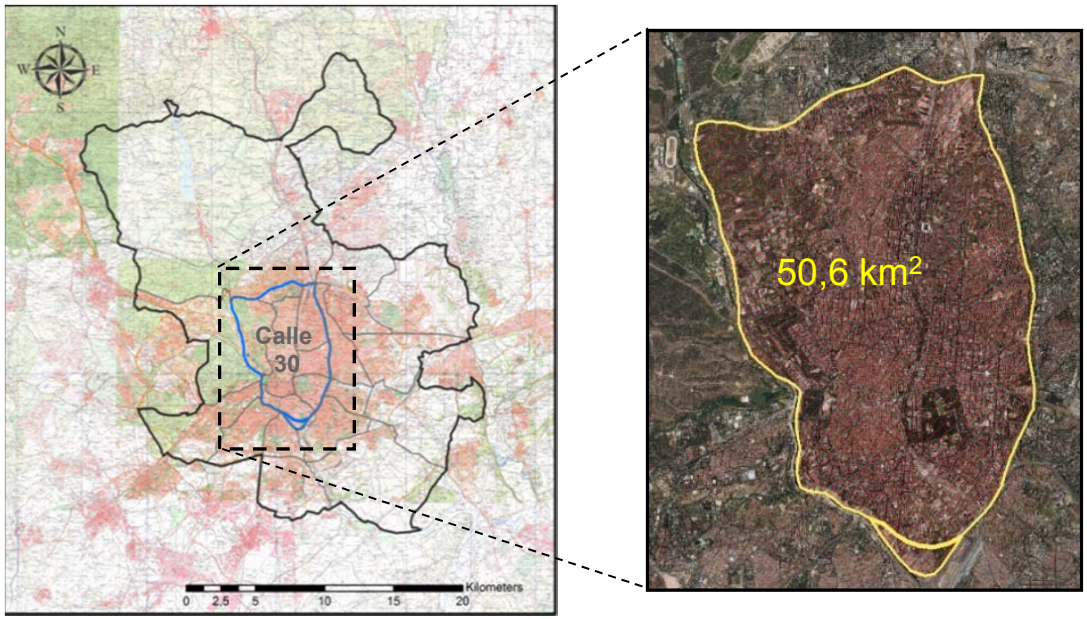
- Integration with the regional traffic model (TDM) for emission computation at link level (15 000 aproximately)
  - 1h intensity and speed from the traffic model
  - Zone-specific fleet composition and age from field campaigns



Borge et al., 2012 (AE)

Temporal and spatial scope of traffic restrictions

- A 10-day period with high stability and low ventilation (winter) was selected, typical of high-pollution episodes (2007 meteorology)
- Restriction measures to be applied inside M30 (ring road)
- Only for working days



- Reference scenario = 2014 (expected situation from the Madrid AQP)
- Same initial and boundary conditions and emissions for non-traffic sources (corresponding period of 2014) for all scenarios

3. Scenarios

- In a first stage 4 scenarios were considered:

A - 20 % reduction of passenger cars
B - 20 % reduction of passenger cars + restrictions for taxis
C - 50 % reduction of passenger cars
D - 50 % reduction of passenger cars + restrictions for taxis

Restriction level

- None of these restrictions apply to residents, emergency and public service vehicles, duty vehicles, etc.
- An additional, more restrictive scenario was considered in a second stage:

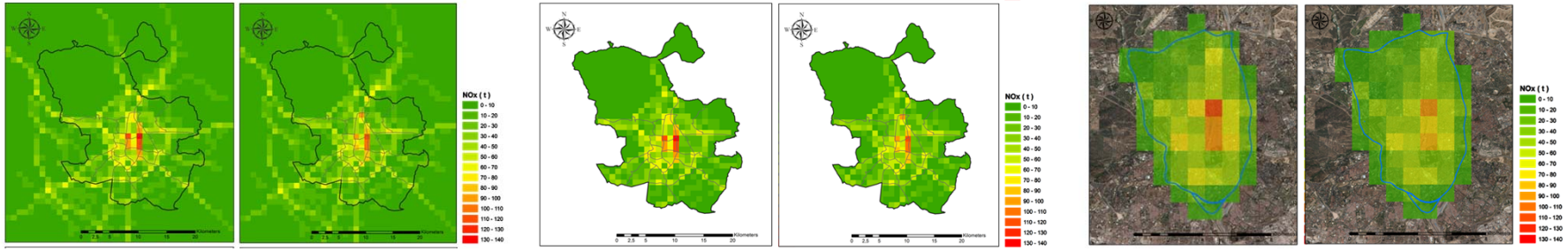
E - 50 % reduction of passenger cars (including residents) + restrictions for taxis

4. Results

Scenarios A-D

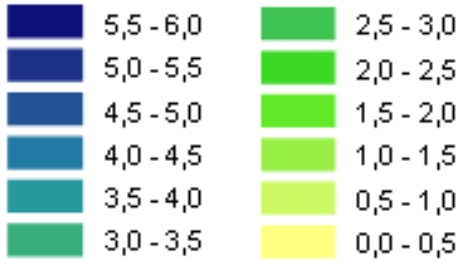
- Emission summary

Scenario	Definition	NO_x emission reduction relative to:		
		Total modelling domain	Madrid municipality	Inner area (M30)
A	20 % reduction of passenger cars	2.1%	3.0%	5.7%
B	20 % reduction of passenger cars + restrictions for taxis	2.5%	3.6%	7.0%
C	50 % reduction of passenger cars	5.7%	7.8%	14.1%
D	50 % reduction of passenger cars + restrictions for taxis	6.1%	8.5%	15.6%

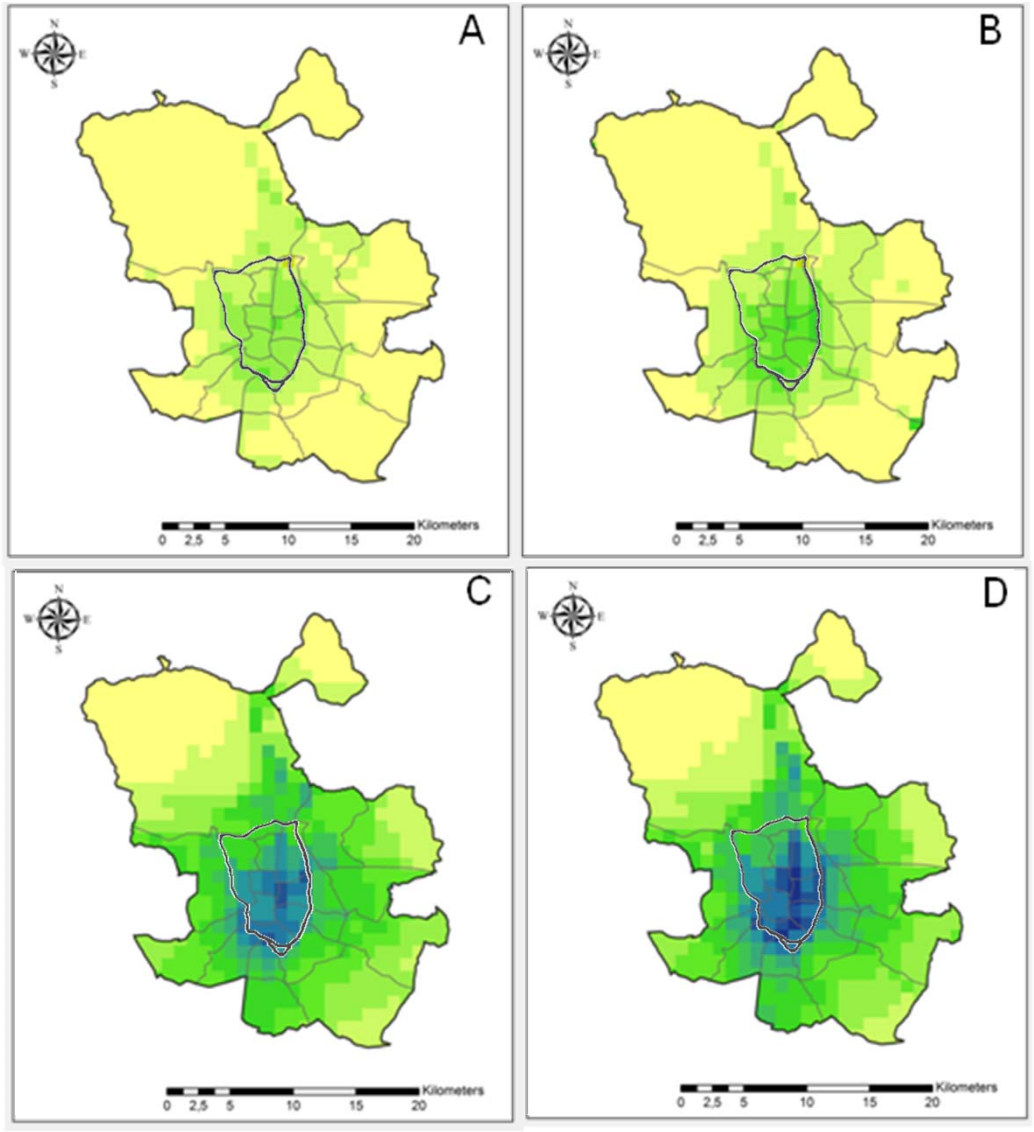


- Air quality summary

  - These measures may achieve improvements of 2-3 μg/m^3 for the 20% reduction and up 6 μg/m^3 for the 50% reduction scenario
  - Roughly 7% decrease in the innermost area for the most restrictive scenario

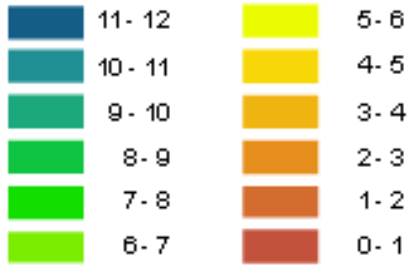


Decrease of average NO_2 (μg/m^3) in the 10-day period

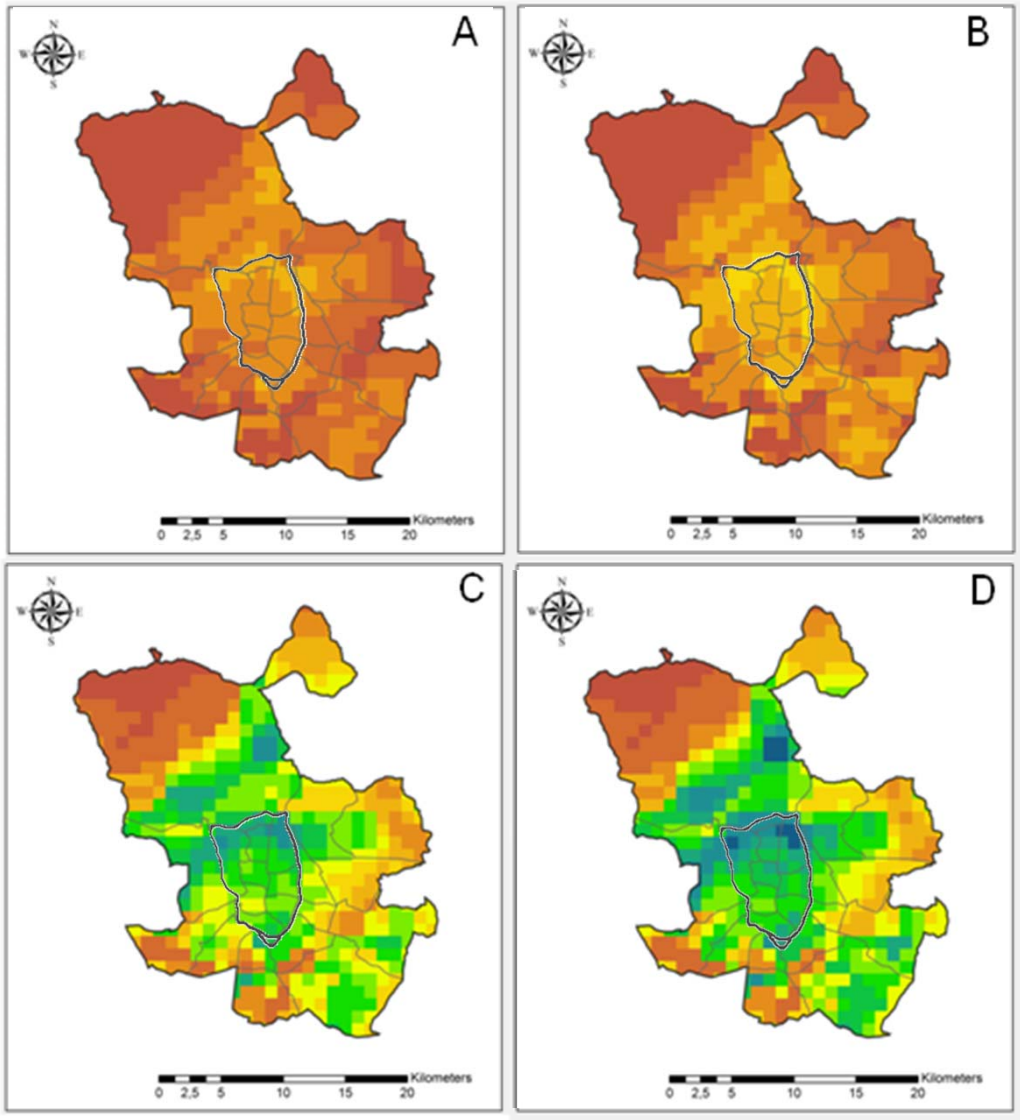


- Air quality summary

  - Concentration peaks may be reduced in the central area of Madrid by 5-7 % (up to 12 ug/m^3) under the most restrictive scenario
  - The effect of taxi restrictions is broadly 1 ug/m^3

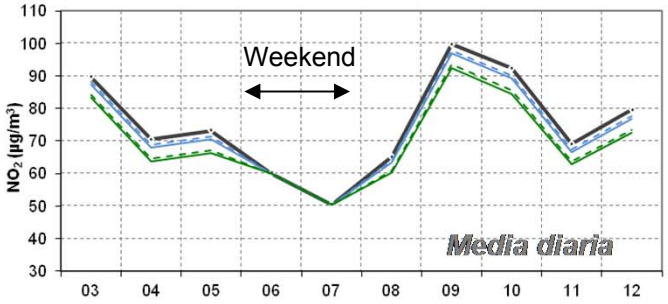


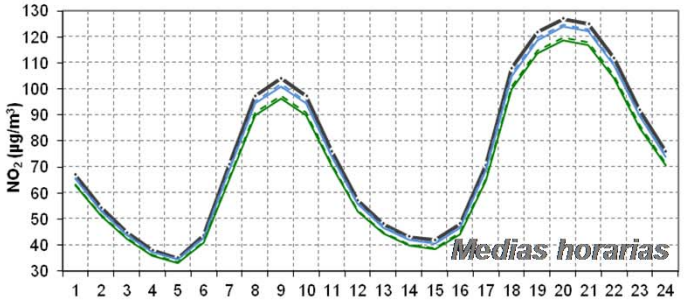
Decrease of maximum 1-h NO_2 (µg/m^3) in the 10-day period



- Analysis of concentration variations in time

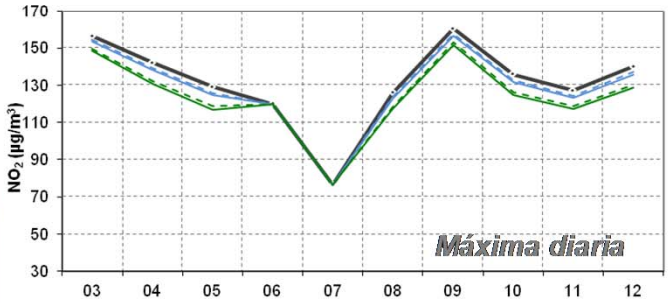
Daily means

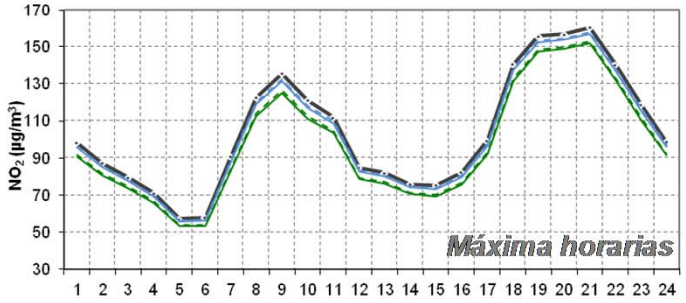




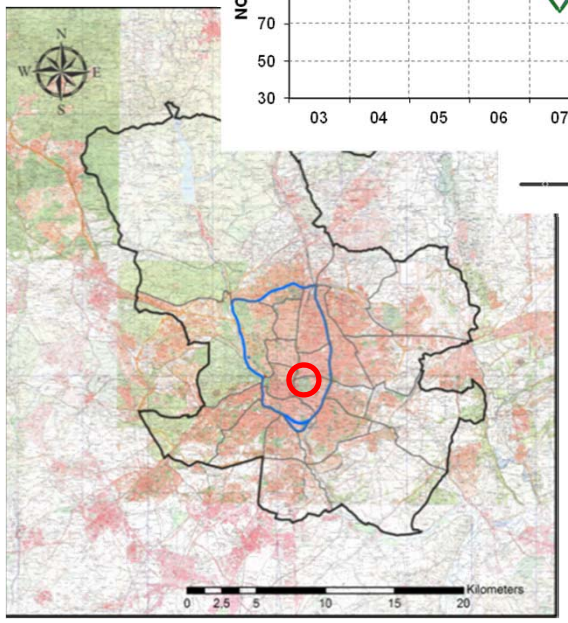
Mean concentration by hour

Daily 1-h maximum concentration





Maximum concentration by hour



BASE A B C D

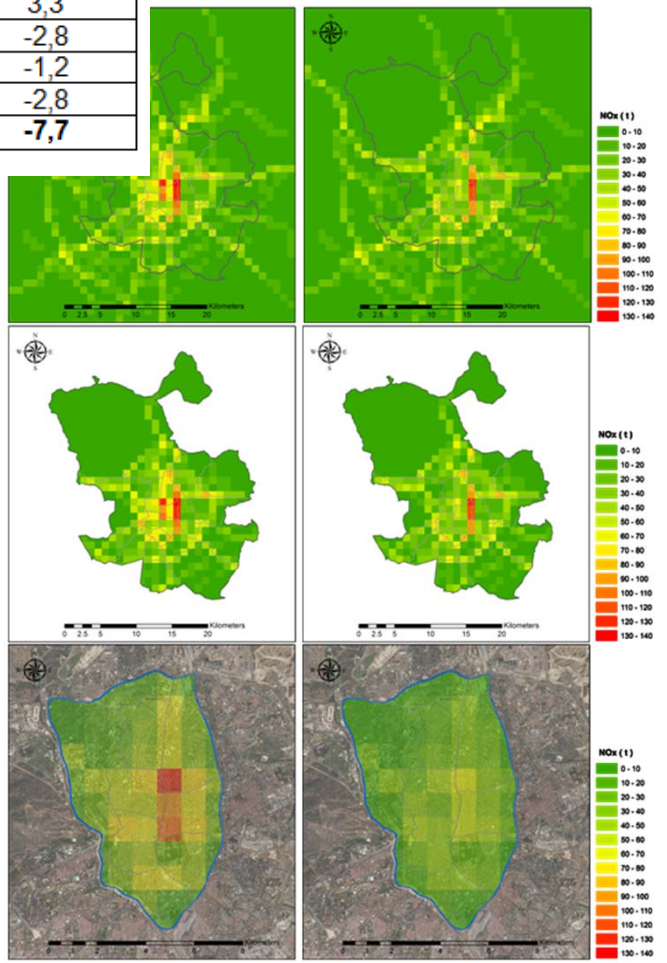
Scenario	NO_2 average concentration (µg/m³)	NO_2 1-h maximum concentration (µg/m³)	NO_2 1-h minimum concentration (µg/m³)	Relative change BASE scenario		
BASE	74.9	160.3	16.0	Average	1-h max	1-h min
A	73.6	157.7	16.0	-1.9%	-1.6%	0.0%
B	73.0	156.6	16.0	-2.6%	-2.3%	0.0%
C	70.4	152.9	16.0	-6.1%	-4.6%	0.0%
D	69.7	151.6	16.0	-7.1%	-5.4%	0.0%

Scenario E

- Emission summary

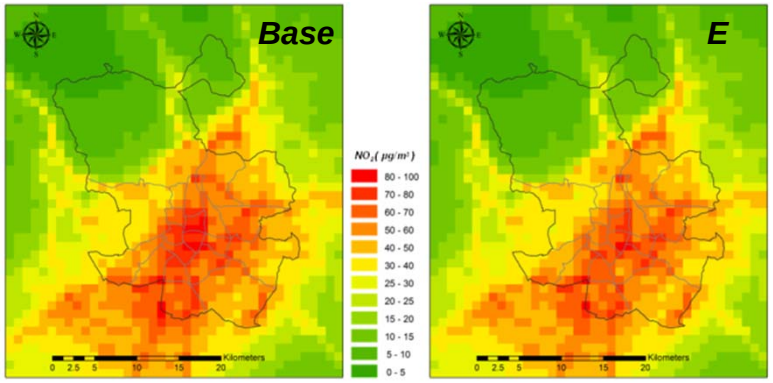
Zone	NO_X emission base scenario (t)	NO_X scenario E (t)	Variation	
			Absolute (t)	Relative (%)
1	198	122	-76	-38,5
2	119	67	-52	-44,0
3	723	395	-327	-45,3
4	234	129	-104	-44,7
5	1047	569	-479	-45,7
6 (M-30)	1094	1130	36	3,3
7	3066	2980	-86	-2,8
8 (M-40)	1487	1470	-18	-1,2
9	9840	9568	-271	-2,8
Total	**17807**	**16430**	**-1378**	**-7,7**

- Global emission reduction of nearly 8% in the modelling domain
- Strong emission reduction inside M-30 (despite mobility reduction an increase of 10 km/h in average speed is expected)
- Slight increase of NO_X emissions in the ring road (3,3%) due to traffic redistribution
- Very small increase of distance travelled outside M-30 and decrease of average speed (< 1 km/h)

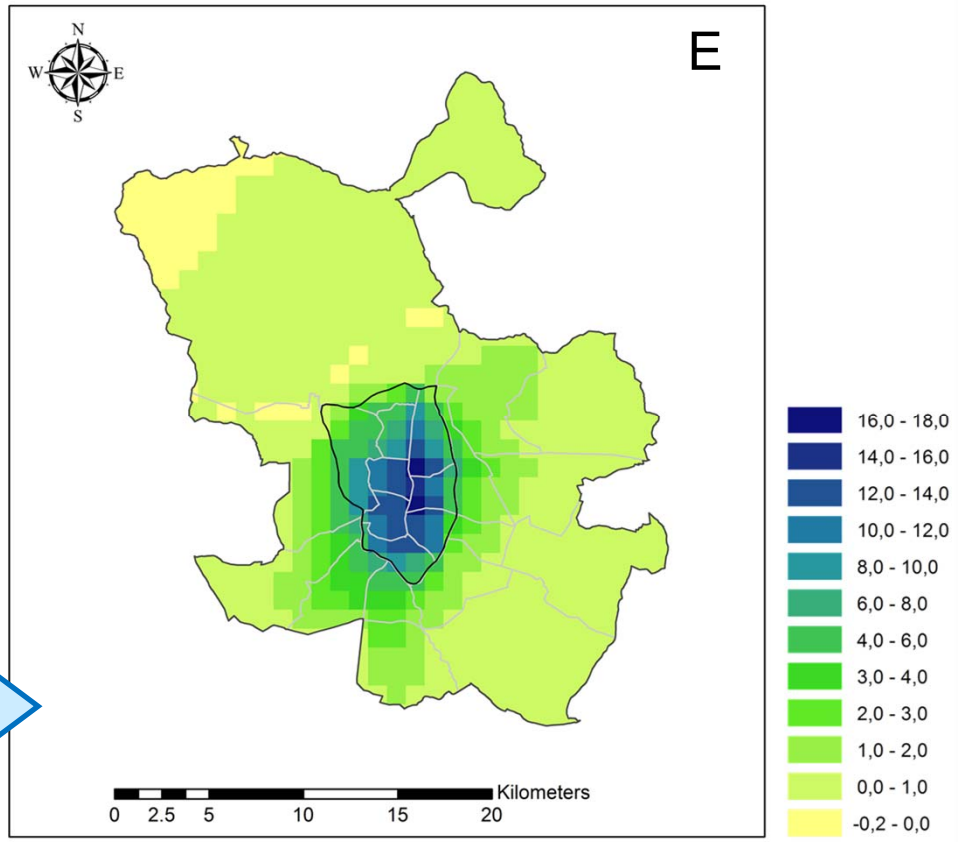


- Air quality summary

- Average decrease of 12% in average NO_2 concentration within M-30
- Maximum reductions up to 17 µg/m^3 (Castellana area)

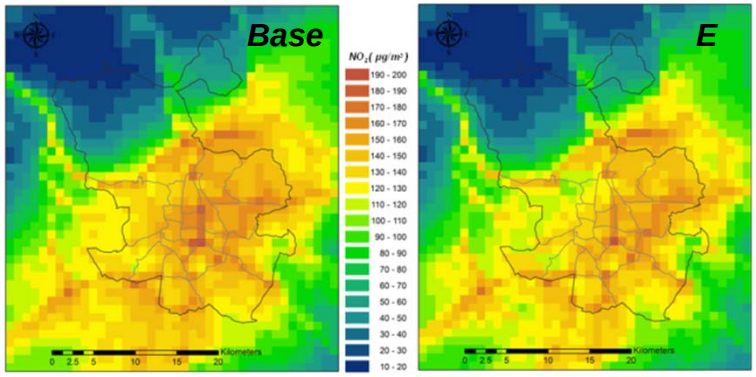


Decrease of average NO_2 (µg/m^3) in the 10-day period

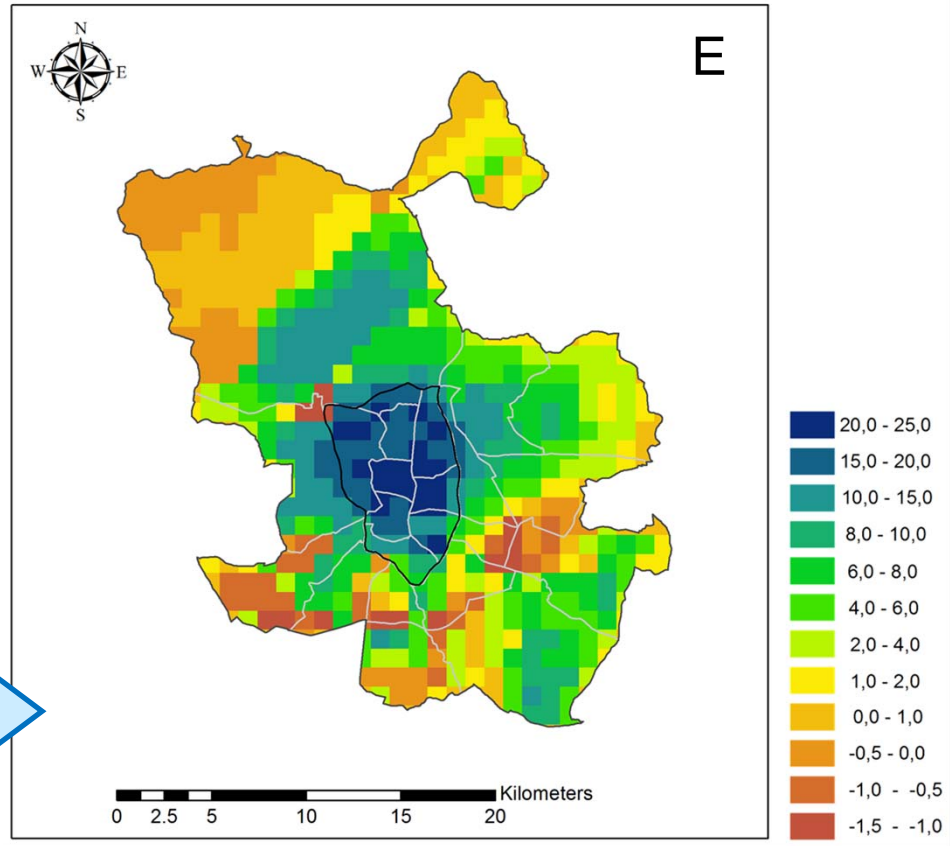


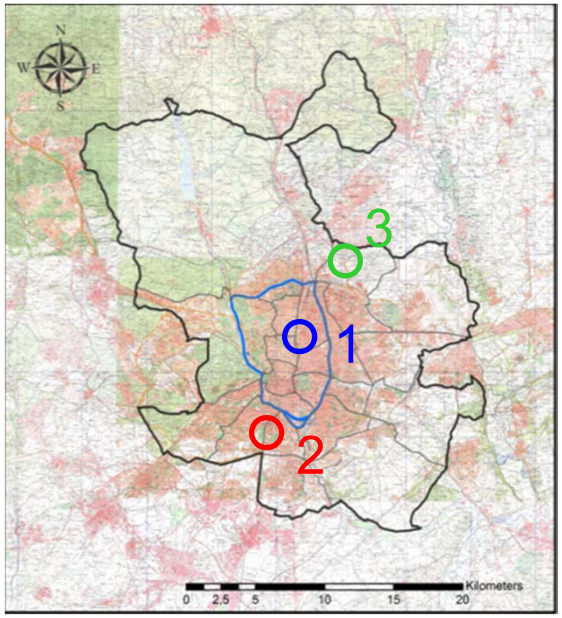
- Air quality summary

- Peak concentration values vary in a similar percentage
- Reductions between 10 and 25 µg/m^3 inside M-30
- Small increments in particular spots outside M-30

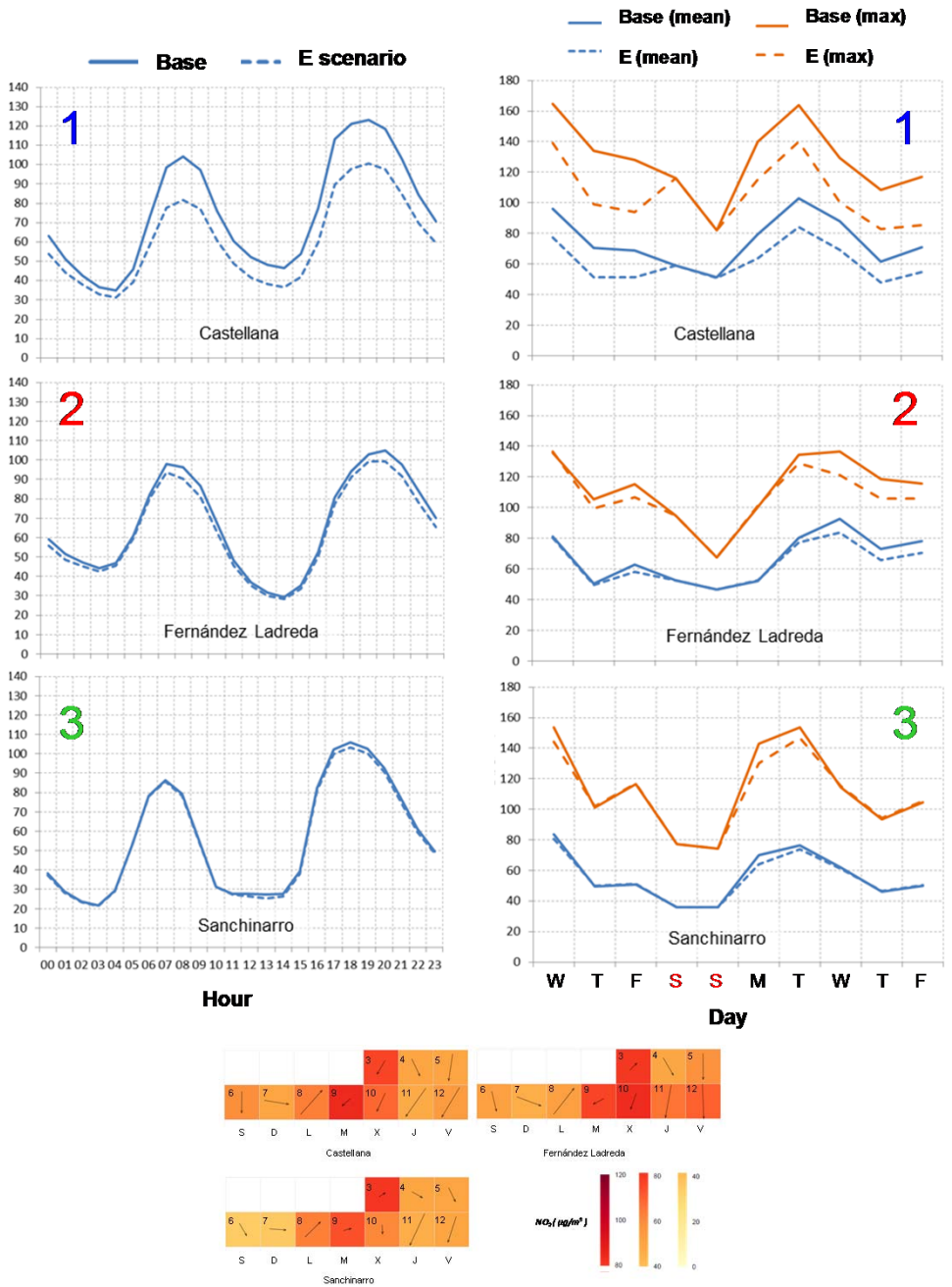


Decrease of maximum 1-h NO_2 (µg/m^3) in the 10-day period





- The effect decreases strongly with distance and becomes highly dependent on wind patterns
- NO_2 reductions grow slowly in time but the effect ceases to exist soon after the restriction is removed



5. Conclusions

- Road traffic is the main responsible of air quality issues in Madrid
- Improving air quality with temporal measures under unfavourable meteorological conditions is very hard
- Temporal traffic restrictions may help to avoid very high pollution levels, and therefore hourly NO_2 limit value exceedances, but only if strong measures are applied in relatively large areas of the city
- Significant improvements in the city centre (reductions of 10-15 $\mu g/m^3$ and 15-25 $\mu g/m^3$ for average and maximum NO_2 concentration respectively) can be achieved by applying a 50% restriction to passenger cars inside M-30, including residents in that area
- A minimum of 2-3 days of application is needed
- The effect of the restriction measures diminishes rapidly with distance, so the reduction in the city outskirts may be negligible depending on meteorological conditions

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- The Madrid City Council provided the traffic model outputs and funded this study.

THANK YOU FOR YOUR ATTENTION!

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